MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1, 2022/2023 (TERM ID 2210)

EME4016 – HEAT TRANSFER

(ME)

6 FEBRUARY 2023
2:30 p.m. – 4:30 p.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question Paper consists of eight pages including the cover page and appendices.
2. Answer ALL four questions. Each question carries 25 marks and the distribution of the marks for each question is given in brackets [ ].
3. Write all your answers in the Answer Booklet provided.

Question 1

(a) Steam flows in a 10 m long steel pipe which is insulated by a layer of plaster. The steel pipe has an inner radius of 2.5 cm and outer radius of 5.0 cm. The thickness of the insulation layer is 2.0 cm. The thermal conductivity of the steel and the insulation layer are given as 45 W/m·K and 0.12 W/m·K, respectively. The ambient temperature is at 25 °C and the convective heat transfer coefficient at the outer surface of the insulation is 100 $W/m^2 \cdot /K$.

(i) Sketch the thermal circuit with proper labellings. **[5 marks]**

(ii) If the inner surface temperature of the steel pipe is 200 °C, determine the temperature at the outer surface of the insulation layer.

[11 marks]

(b) A (70 mm × 115 mm × 240 mm) brick is required to be cooled from 1200 °C to 300 °C within a day. The properties of the brick are given as $\rho = 1800$ kg/m^3 and $k = 1.2$ W/m·K. The ambient air temperature is 25 °C and the convective heat transfer coefficient is 5 $W/m^2 \cdot /K$. Determine the specific heat of the brick.

[9 marks]

Continued...

Question 2

(a) Air at 15 °C flows through a 4 m long and 6 cm diameter pipe at a flow rate of 0.01 kg/s. The surface temperature of the pipe is 120 °C. Evaluate the properties at 50 °C.

(i) Determine the air outlet temperature. Explain if there is a need to re-evaluate the properties at a different temperature. **[12 marks]**

(ii) Determine the total heat transfer rate from the duct to the air. **[3 marks]**

(b) Air at 30 °C is flowing at a rate of 2 m/s over the top surface of a 2 m × 0.5 m flat plate which is heated uniformly at a temperature of 210 °C.

(i) Determine the heat transfer rate from the plate if the air is flowing parallelly to the 2 m side. **[7 marks]**

(ii) Estimate if the heat transfer rate will be enhanced if the air flows parallelly to the 0.5 m side. Explain your answer without further calculation. **[3 marks]**

Continued...

Question 3

(a) Given two identical infinite parallel non-black plates, prove that the net radiative heat transfer between the plates is

$$q_{1-2} = \frac{A\sigma(T_1^4 - T_2^4)}{\frac{2}{\epsilon} - 1}$$

when the emissivity, ϵ of both plates are assumed to be the same. **[7 marks]**

(b) Two parallel plates with surface area of 1 m^2 are at temperatures T_1 = 500 K and T_2 = 300 K, with emissivities ϵ_1 = 0.5 and ϵ_2 = 0.2, respectively.

(i) Sketch the thermal network with proper labellings. Given the Stefan-Boltzmann constant is 5.67×10^{-8} $W/m^2 \cdot K^4$, determine the net heat transfer by radiation between the plates. **[10 marks]**

(ii) The parallel plates are placed in a large room at room temperature. Without solving, sketch the thermal radiation network for the radiation exchange among the three surfaces and labelling all the nodes and resistance.
Hint: Assume the large room as a blackbody. **[8 marks]**

Continued...

Question 4

(a) A 1 m × 1 m section of the plate at 150 °C is to be cooled by attaching 10000 pieces of 5 cm long and 5 mm diameter of aluminum pins. The thermal conductivity of the pins are 240 W/m·K. The surrounding temperature is 20 °C with heat transfer coefficient on the surface is 10 $W/m^2 \cdot K$. Assume the heat transfer from the fin tips is negligible. Determine:

(i) Total heat transfer rate from the hot surface **[13 marks]**

(ii) Overall fin effectiveness **[4 marks]**

(b) Water at 20 °C is to be heated by solar heated air which enters the double pipe parallel flow heat exchanger at 110 °C and at the same flow rate as water, which is 0.5 kg/s. Given the specifc heat of water and air are 4180 J/kg·K and 1010 J/kg·K, respectively. Determine the actual heat transfer rate of the heat exchanger if the NTU of the heat exchanger is 2.

[8 marks]

Continued...

Appendix A: Properties of air at 1 atm pressure

Properties of air at 1 atm pressure

Temp., T, °C	Density, ρ, kg/m³	Specific Heat, C_p, J/kg · °C	Thermal Conductivity, k, W/m · °C	Thermal Diffusivity, α, m²/s	Dynamic Viscosity, μ, kg/m · s	Kinematic Viscosity, ν, m²/s	Prandtl Number, Pr
−150	2.866	983	0.01171	4.158×10^{-6}	8.636×10^{-6}	3.013×10^{-6}	0.7246
−100	2.038	966	0.01582	8.036×10^{-6}	1.189×10^{-6}	5.837×10^{-6}	0.7263
−50	1.582	999	0.01979	1.252×10^{-5}	1.474×10^{-5}	9.319×10^{-6}	0.7440
−40	1.514	1002	0.02057	1.356×10^{-5}	1.527×10^{-5}	1.008×10^{-5}	0.7436
−30	1.451	1004	0.02134	1.465×10^{-5}	1.579×10^{-5}	1.087×10^{-5}	0.7425
−20	1.394	1005	0.02211	1.578×10^{-5}	1.630×10^{-5}	1.169×10^{-5}	0.7408
−10	1.341	1006	0.02288	1.696×10^{-5}	1.680×10^{-5}	1.252×10^{-5}	0.7387
0	1.292	1006	0.02364	1.818×10^{-5}	1.729×10^{-5}	1.338×10^{-5}	0.7362
5	1.269	1006	0.02401	1.880×10^{-5}	1.754×10^{-5}	1.382×10^{-5}	0.7350
10	1.246	1006	0.02439	1.944×10^{-5}	1.778×10^{-5}	1.426×10^{-5}	0.7336
15	1.225	1007	0.02476	2.009×10^{-5}	1.802×10^{-5}	1.470×10^{-5}	0.7323
20	1.204	1007	0.02514	2.074×10^{-5}	1.825×10^{-5}	1.516×10^{-5}	0.7309
25	1.184	1007	0.02551	2.141×10^{-5}	1.849×10^{-5}	1.562×10^{-5}	0.7296
30	1.164	1007	0.02588	2.208×10^{-5}	1.872×10^{-5}	1.608×10^{-5}	0.7282
35	1.145	1007	0.02625	2.277×10^{-5}	1.895×10^{-5}	1.655×10^{-5}	0.7268
40	1.127	1007	0.02662	2.346×10^{-5}	1.918×10^{-5}	1.702×10^{-5}	0.7255
45	1.109	1007	0.02699	2.416×10^{-5}	1.941×10^{-5}	1.750×10^{-5}	0.7241
50	1.092	1007	0.02735	2.487×10^{-5}	1.963×10^{-5}	1.798×10^{-5}	0.7228
60	1.059	1007	0.02808	2.632×10^{-5}	2.008×10^{-5}	1.896×10^{-5}	0.7202
70	1.028	1007	0.02881	2.780×10^{-5}	2.052×10^{-5}	1.995×10^{-5}	0.7177
80	0.9994	1008	0.02953	2.931×10^{-5}	2.096×10^{-5}	2.097×10^{-5}	0.7154
90	0.9718	1008	0.03024	3.086×10^{-5}	2.139×10^{-5}	2.201×10^{-5}	0.7132
100	0.9458	1009	0.03095	3.243×10^{-5}	2.181×10^{-5}	2.306×10^{-5}	0.7111
120	0.8977	1011	0.03235	3.565×10^{-5}	2.264×10^{-5}	2.522×10^{-5}	0.7073
140	0.8542	1013	0.03374	3.898×10^{-5}	2.345×10^{-5}	2.745×10^{-5}	0.7041
160	0.8148	1016	0.03511	4.241×10^{-5}	2.420×10^{-5}	2.975×10^{-5}	0.7014
180	0.7788	1019	0.03646	4.593×10^{-5}	2.504×10^{-5}	3.212×10^{-5}	0.6992
200	0.7459	1023	0.03779	4.954×10^{-5}	2.577×10^{-5}	3.455×10^{-5}	0.6974
250	0.6746	1033	0.04104	5.890×10^{-5}	2.760×10^{-5}	4.091×10^{-5}	0.6946
300	0.6158	1044	0.04418	6.871×10^{-5}	2.934×10^{-5}	4.765×10^{-5}	0.6935
350	0.5664	1056	0.04721	7.892×10^{-5}	3.101×10^{-5}	5.475×10^{-5}	0.6937
400	0.5243	1069	0.05015	8.951×10^{-5}	3.261×10^{-5}	6.219×10^{-5}	0.6948
450	0.4880	1081	0.05298	1.004×10^{-4}	3.415×10^{-5}	6.997×10^{-5}	0.6965
500	0.4565	1093	0.05572	1.117×10^{-4}	3.563×10^{-5}	7.806×10^{-5}	0.6986
600	0.4042	1115	0.06093	1.352×10^{-4}	3.846×10^{-5}	9.515×10^{-5}	0.7037
700	0.3627	1135	0.06581	1.598×10^{-4}	4.111×10^{-5}	1.133×10^{-4}	0.7092
800	0.3289	1153	0.07037	1.855×10^{-4}	4.362×10^{-5}	1.326×10^{-4}	0.7149
900	0.3008	1169	0.07465	2.122×10^{-4}	4.600×10^{-5}	1.529×10^{-4}	0.7206
1000	0.2772	1184	0.07868	2.398×10^{-4}	4.826×10^{-5}	1.741×10^{-4}	0.7260
1500	0.1990	1234	0.09599	3.908×10^{-4}	5.817×10^{-5}	2.922×10^{-4}	0.7478
2000	0.1553	1264	0.11113	5.664×10^{-4}	6.630×10^{-5}	4.270×10^{-4}	0.7539

Note: For ideal gases, the properties C_p, k, μ, and Pr are independent of pressure. The properties ρ, ν, and α at a pressure P (in atm) other than 1 atm are determined by multiplying the values of ρ at the given temperature by P and by dividing ν and α by P.

Source: Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Original sources: Keenan, Chao, Keyes, Gas Tables, Wiley, 198; and Thermophysical Properties of Matter, Vol. 3: Thermal Conductivity, Y. S. Touloukian, P. E. Liley, S. C. Saxena, Vol. 11: Viscosity, Y. S. Touloukian, S. C. Saxena, and P. Hestermans, IFI/Plenum, NY, 1970, ISBN 0-306067020-8.

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Appendix B: List of Nusselt Number correlations

External Forced Convection:

The local Nusselt number at location x over a flat plate

Laminar: $\mathrm{Nu}_x = \dfrac{h_x x}{k} = 0.332\,\mathrm{Re}_x^{0.5}\,\mathrm{Pr}^{1/3}$ $\quad \mathrm{Pr} > 0.6$

Turbulent: $\mathrm{Nu}_x = \dfrac{h_x x}{k} = 0.0296\,\mathrm{Re}_x^{0.8}\,\mathrm{Pr}^{1/3}$ $\quad 0.6 \le \mathrm{Pr} \le 60$, $5 \times 10^5 \le \mathrm{Re}_x \le 10^7$

The average Nusselt number

Laminar: $\mathrm{Nu} = \dfrac{hL}{k} = 0.664\,\mathrm{Re}_L^{0.5}\,\mathrm{Pr}^{1/3}$ $\quad \mathrm{Re}_L < 5 \times 10^5,\ \mathrm{Pr} > 0.6$

Turbulent: $\mathrm{Nu} = \dfrac{hL}{k} = 0.037\,\mathrm{Re}_L^{0.8}\,\mathrm{Pr}^{1/3}$ $\quad 0.6 \le \mathrm{Pr} \le 60$, $5 \times 10^5 \le \mathrm{Re}_L \le 10^7$

Internal Forced Convection:

Circular tube, laminar ($\dot{q}_s$ = constant): $\mathrm{Nu} = \dfrac{hD}{k} = 4.36$

Circular tube, laminar (T_s = constant): $\mathrm{Nu} = \dfrac{hD}{k} = 3.66$

For a circular tube of length L subjected to constant surface temperature, the average Nusselt number for the thermal entrance region (hydrodynamically developed flow)

$$Nu = 3.66 + \frac{0.065\,(D/L)\,\mathrm{Re}\,\mathrm{Pr}}{1 + 0.04[(D/L)\,\mathrm{Re}\,\mathrm{Pr}]^{2/3}}$$

The average Nu number for the hydrodynamically and thermally developing laminar flow (combined entry length) in a circular tube can be determined from *(Sieder and Tate)*

$$\mathrm{Nu} = 1.86\left(\frac{\mathrm{Re}\,\mathrm{Pr}\,D}{L}\right)^{1/3}\left(\frac{\mu_b}{\mu_s}\right)^{0.14}$$

where all the properties are evaluated at T_b, except μ_s which is evaluated at T_s.

For fully developed turbulent flow in smooth tubes, a simple relation for Nu number can be obtained by

$$Nu_D = 0.023\,Re_D^{0.8}\,Pr^n \quad \begin{cases} n = 0.3 \,(T_s < T_m) \\ n = 0.4 \,(T_s > T_m) \end{cases} \quad \begin{bmatrix} 0.7 \le Pr \le 160 \\ Re_D \ge 10000 \\ L/D \ge 10 \end{bmatrix}$$

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Appendix C: Effectiveness relations for heat exchangers

Heat exchanger type	Effectiveness relation
1 *Double pipe:*	
Parallel-flow	$\varepsilon = \dfrac{1 - \exp[-\text{NTU}(1+c)]}{1+c}$
Counter-flow	$\varepsilon = \dfrac{1 - \exp[-\text{NTU}(1-c)]}{1 - c\exp[-\text{NTU}(1-c)]}$
2 *Shell-and-tube:* One-shell pass 2, 4,...tube passes	$\varepsilon = 2\left\{1 + c + \sqrt{1+c^2}\,\dfrac{1+\exp[-\text{NTU}\sqrt{1+c^2}]}{1-\exp[-\text{NTU}\sqrt{1+c^2}]}\right\}^{-1}$
3 *Cross-flow (single-pass)* Both fluids unmixed	$\varepsilon = 1 - \exp\left\{\dfrac{\text{NTU}^{0.22}}{c}[\exp(-c\ \text{NTU}^{0.78}) - 1]\right\}$
C_{max} mixed, C_{min} unmixed	$\varepsilon = \dfrac{1}{c}(1 - \exp\{-c[1 - \exp(-\text{NTU})]\})$
C_{min} mixed, C_{max} unmixed	$\varepsilon = 1 - \exp\left\{-\dfrac{1}{c}[1 - \exp(-c\ \text{NTU})]\right\}$
4 *All heat exchangers with* $c = 0$	$\varepsilon = 1 - \exp(-\text{NTU})$

End of Paper